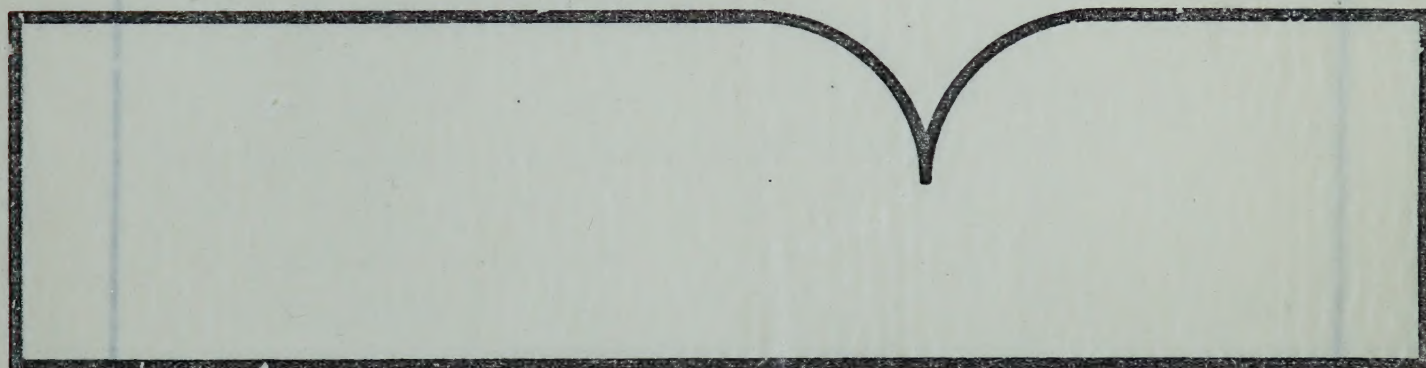PB80-120397

MELTING ICEBERGS TO PRODUCE FRESH WATER AND
MECHANICAL ENERGY

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Produce Fresh Water and

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(U.S.) Department of Agriculture, Washington, DC

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NOTICE

The Government - owned invention described herein is available for licensing. Inquiries and requests for licensing information and application should be addressed to:

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MELTING ICEBERGS TO PRODUCE FRESH WATER

AND MECHANICAL ENERGY

Abstract of the Disclosure

Fresh water and mechanical energy are obtained from melting
of icebergs. Warm surface seawater is contacted with a fluid,
which is vaporized. The resulting vapor is used to generate
mechanical energy and then is condensed by contacting it with cold
5   melt water from the iceberg. The fluid is regenerated with a
concomitant elevation in the temperature of the melt water. The
warmer melt water is cycled to the body of the iceberg to
facilitate its melting and produce additional cold melt water,
which is apportioned as fresh water and water cycled to condense
10   the aforesaid vapor.

In an alternate embodiment of the invention warm seawater
is evaporated at reduced pressure. Mechanical energy is generated
from the vapor, which is then condensed by direct and intimate
contact with cold melt water from the iceberg. The resultant
15   fresh water is a mixture of condensed vapor and melt water from
the iceberg and has a temperature greater than the cold melt water.
This fresh water mixture is contacted with the body of the iceberg
to further melt it; part of the cold melt water is separated as
fresh water and the remainder is cycled for use in condensing the
20   vapor from the warm surface seawater.

Background of the Invention

1. Field of the Invention:

This invention relates to and has among its objects the
provision of novel methods and apparatus for melting icebergs.
25   It is a particular object of the invention to provide both fresh

water and mechanical energy from the melting of icebergs. Further
objects of the invention will be evident from the following
description wherein parts and percentages are by weight unless
otherwise specified.

5   .. Description of the Prior Art:

The most productive agricultural regions are arid regions
because they are rich in solar energy and their soils are high
in nutrients. However, these agriculturally productive arid
regions must obtain irrigation water from humid areas. To
10   significantly extend crop acreage, therefore, it is necessary
to expand irrigation.

One solution proposed for providing an inexpensive source
of irrigation water for arid regions is the use of melt water
from icebergs. The annual yield of fresh water from icebergs
15   is estimated at 12,000 cubic kilometers, the total world iceberg
accumulation being six times this amount. Annual yield of fresh
water from Antartic icebergs alone would provide sufficient
water to irrigate about 90 million hectares or 40% of currently
irrigated land.

20   A number of modes of iceberg transport have been disclosed:
Science Digest, Vol. 39, page 1 (1956); Water Resources Journal,
Vol. 100, page 1 (1974); Bull. Atom. Scient., Vol. 29, page 35
(1973); Journal of Glaciology, Vol. 12, page 207 (1973); Ocean
Industry, Vol. 8, page 28 (1973); and New Scientist, Vol. 75,
25   page 11 (1977). It has been calculated that icebergs could be
delivered to the United States at a cost that would make them
highly attractive as a source of both irrigation and drinking
water.

The major problem in obtaining water from icebergs is the
30   large expenditure of energy required to melt an iceberg. Indeed,
the energy necessary to melt an iceberg is about 2,000 times

greater than the energy needed to transport it. Solar energy has
been considered, but it is postulated that direct contact of the
desert sun of Saudi Arabia on an iceberg would melt only
approximately 10 vertical meters of iceberg per year. Another
suggestion as an energy source is waste heat from coastal
electric power plants. However, this would require bringing
an iceberg close to coastal boundaries, which presents some
difficulty because of the depth of an iceberg and the necessity
for running pipe lines to convey the source of waste heat to the
iceberg and the fresh water from the iceberg to the coast.

The oceans of the world represent a vast source of solar
energy and the idea of recovering this energy is old in the
art, being first proposed in 1881. Ocean Thermal Energy
Conversion (here nafter referred to as OTEC) has been described
recently. Basically, OTEC involves converting the difference
in temperatures of warmer surface sea water and cooler deep sea
water into mechanical energy (Solar Energy, Vol. 18, pages 81-92
(1976)). In closed cycle OTEC a fluid, such as ammonia or a
halogenated hydrocarbon, is heated with warm seawater through a
heat exchanging boundary to vaporize it. After expansion through
a turbine, the vapor is condensed on a heat exchanging surface
with cold seawater (Mechanical Engineering, Vol. 88, page 41,
(1966); Chem. Eng. News, Vol. 54, page 19 (1976); and Solar
Energy, Vol. 20, page 259 (1976)). Open cycle OTEC (U.S. Patent
3,967,449) is a simpler concept than closed cycle OTEC since
cool seawater is employed directly to condense vaporized warm
seawater. However, even open cycle OTEC has the disadvantage
that heat exchangers are required in order to produce fresh
water from seawater.

Summary of the Invention

The invention described herein provides means for supplying
low-cost energy for melting of icebergs to yield fresh water and

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mechanical energy with the avoidance of the aforementioned problems. In the present method warm surface seawater is employed to convert a liquid or fluid to a working vapor from which mechanical energy is generated. Then, the vapor is

5   contacted with cold melt water from the iceberg to condense the working vapor to the liquid state. The temperature of the aforesaid cold melt water is raised by the conversion of the vapor to liquid, and the resulting warmer water is cycled to the iceberg to facilitate melting thereof and produce

10   additional cold melt water. A portion of this cold melt water is separated and removed and the remainder is employed to condense the working vapor as described above.

An apparatus in accordance with the invention comprises means for treating warm surface seawater to produce a vapor

15   from a liquid or fluid, said means communicating with means for generating mechanical energy from the vapor. The latter means further communicates with means for contacting the vapor with cold melt water from an iceberg to condense the vapor and regenerate the working fluid thereby raising the temperature of

20   the cold melt water. Means for contacting the warmer water with the body of the iceberg to produce cold melt water cooperates with the latter means. The present apparatus further includes means for separating and removing a portion of the cold melt water and means for recycling a portion of this cold melt water

25   to condense the aforesaid vapor and produce working fluid.

The method and apparatus of the invention has the advantage of substantially reducing the expense of money and energy in obtaining fresh water and mechanical energy from icebergs. Furthermore, cumbersome procedures found in prior art approaches

30   are avoided in the instant invention.

In an alternate and preferred embodiment of the present invention the liquid or fluid is warm surface seawater, which

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is vaporized and treated to obtain mechanical energy therefrom, and then the vapor is condensed by direct and intimate contact with cold melt water from an iceberg yielding a mixture of iceberg melt water and condensed vapor having a temperature greater than the cold melt

5   water. The warmer mixture is then cycled to the iceberg.

This particular embodiment of the invention has a number of advantages over the embodiments wherein a liquid or fluid other than warm seawater is employed. The primary advantage of this embodiment is that fresh water can be obtained without employing

10   a heat exchanging surface. Vaporized seawater can be condensed by intimate mixing with cold iceberg melt water resulting in a fresh water mixture free of salt. In the method of U.S. 3,967,449, fresh water free of salt can be produced only by employing a heat exchanger. The method and apparatus disclosed in the patent

15   yields a mixture containing salt water, which would be unfit, without further purification, for drinking, irrigation, and the like.

An apparatus in accordance with the aforesaid preferred embodiment comprises means for evaporating warm surface seawater

20   to produce water vapor communicating with means for generating mechanical energy from said vapor and means for condensing said vapor by contacting it directly and intimately with cold melt water from an iceberg to produce fresh water comprising a mixture of condensed vapor and melt water from the iceberg having a

25   temperature greater than the cold melt water. Also included in the above apparatus are means for contacting the warmer fresh water mixture with the body of the iceberg to melt it, means for separating a portion of the cold melt water as fresh water, and means for cycling the remainder of the cold melt water to condense the aforementioned vapor.

Brief Description of the Drawings

Fig. 1 is a diagrammatic sketch depicting one embodiment of the present invention.

Fig. 2 is a diagrammatic sketch depicting an alternate embodiment of the instant invention.

Fig. 3 is a diagrammatic sketch of part of the present invention depicting one embodiment for melting an iceberg.

Fig. 4 is a three dimensional sketch of part of the present invention depicting another embodiment for melting an iceberg.

Fig. 5 is a three dimensional sketch of part of the present invention depicting a third embodiment for melting an iceberg.

Description of the Preferred Embodiments

The invention is next described in detail with reference to the annexed drawings. Referring to Fig. 1, one end of inlet pipe 10 communicates with warm surface seawater and the other end of 10 is secured to evaporator 11. Water exhaust pump 12 is attached to outlet pipe 34 between 11 and the seawater. Eleven may take the form of a conventional spray evaporator or film evaporator; other types of evaporative units will be suggested to those skilled in the art. Evaporator 11 is connected to condensing unit 13, turbine 14 by means of pipe 15, and vacuum pump 49 by means of pipe 50. Unit 13 includes pipe 16 with perforations at one end which allow a spray (or thin film) of cold melt water to be projected in a generally downward direction. The other end of 16 communicates with iceberg 17 as does one end of pipe 18, connected to pump 19 and condensing unit 13.

In operation vacuum pump 49 evacuates units 13 and 11 and pipe 15 causing warm surface seawater to flow by means of 10 into evaporator 11 wherein it is vaporized under reduced pressure usually about 5-25 millimeters (mm) of mercury. The vapor passes into turbine 14 and generates mechanical energy because the vapor is expanded since the pressure on the condensing unit side of the turbine (6-10 mm of mercury) is less than on the

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evaporator side. From turbine 14 the vapor enters unit 13 wherein
it contacts cold melt water from iceberg 17 delivered, as a spray
or film, by pipe 16, which is perforated in that portion inside
unit 13. The vapor is condensed to the liquid state upon contact
5   with the cold melt water and the mixture of melt water from the
iceberg and condensed vapor, i.e., fresh water 20, is pumped by
19 through 18 to iceberg 17. It is a characteristic of fresh
water mixture 20 that its temperature is greater than that of the
cold melt water from 17 because of the heat generated during the
10   condensation.

Fresh water 20 is contacted with iceberg 17 to facilitate
melting thereof. Three ways in which this contact is realized
are depicted in Figs. 3-5. Referring to Fig. 3 a pool or lake
21 is formed on the top of 17 and contains cold melt water 22.
15   Floating insulating means 23, e.g., reflective plastic sheets equipped
with air pockets, thin, light pieces of polyurethane foam, and the
like, covers a substantial portion of the top of lake 21. The end
of pipe 18 which communicates with 17 contains outlet holes 24,
which allow fresh water 20 to enter lake 21 at one end. Since
20   the temperature of 20 is greater than 22, melting of the iceberg
occurs and the amount of cold melt water from the iceberg in lake
21 increases. Pipe 16 with inlet tubes 25 is situated at the end
of lake 21 opposite the end housing pipe 18. Cold melt water from
2' passes to condensing unit 13 by means of pipe 16. Also located
25   at this end of 21 is pipe 27, which carries away a portion of 22
for use as fresh water for drinking, irrigation, etc.

In the embodiment depicted in Fig. 4 insulating encirclement
28, e.g., double layer plastic sheet equipped with air pockets,
sheets of foamed polymer, and the like, covers all but the top
portion of 17. In effect 28 forms a moat 29 around the iceberg
which contains cold melt water from the iceberg. Pipe 18 has
outlet tubes 48 that project fresh water 20 over the top of 17,

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shielded by insulating shroud 30, again an insulating polymer sheet,
which also serves the function of reducing the head loss of water flow
over the iceberg and, therefore, should be airtight. The elevated
temperature of 20 facilitates melting of the iceberg and cold melt
water 22 collects in 29 from which it is cycled to 13 by means of
16 with a portion removed as fresh water through pipe 27.

Fig. 5 illustrates an embodiment similar to that of Fig. 4. In
Fig. 5 pipe 18 delivers warm fresh water 20 to one side of iceberg 17.
Cold melt water 22 is removed also from one of the sides by means of
pipe 16, which carries 22 to condensing unit 13. As in the Fig. 4
embodiment pipe 27 removes a portion of cold melt water 22 as fresh
water. Alternately, 22 may be removed from the bottom side of the
iceberg; thus the term side as applied above refers to both vertical
sides and the bottom side.

It is also within the compass of the invention to combine the
embodiments of Figs. 3 and 5 and thus melt the iceberg both from
the top and from the sides and bottom as well.

An alternate embodiment of the present invention is depicted in
Fig. 2. Warm surface seawater flows through pipe 32 into an evaporative
heat exchanger 33 comprising a chamber, outlet pipe 34 with water
exhaust pump 31 and standard heat exchanger 35 containing fluid 36.
(In an alternate embodiment warm surface seawater is first vaporized
and the vapors are passed into chamber 33.) The boiling point of 36
should be the same as the temperature of the warm surface seawater or
below. Fluids that can be employed, by way of illustration, are liquid
ammonia, liquid propane, liquid fluorinated and chlorinated hydrocarbons,
and the like. Fluid 36 is vaporized by warm surface seawater to give
working vapor 37, which is passed through demister 51, which removes
water from the vapor, and then through turbine 38 into pipe 39 and then
into condensing unit 40. As in the Fig. 1 embodiment, the pressure on the
condensing unit side of the turbine is less than that on the vaporizer side
and the difference in pressure results in the generation of mechanical
energy as 37 passes (expands) through turbine 38. Vapor 37 entering 40
is converted to fluid 36 on contact with heat exchanging unit 41 filled

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with cold melt water 22 from the iceberg. The condensed fluid is
collected in reservoir 42, comprising part of unit 40. From 42
fluid 36 is pumped along pipe 43 by means of circulation pump 44 to
heat exchanger 35 by means of pipe 45. Cold melt water from 17 is
5   pumped through 41 by means of pump 46. After passing through 35 the
temperature of 22 is raised because of the conversion of vapor 37 into
fluid 36. Pump 46 conveys the warmer melt water along pipe 47 to
iceberg 17 where it is employed to facilitate melting of the iceberg.
It should be evident that the manner of collecting and removing cold
10   melt water 22 and of receiving warmer melt water for melting of the
iceberg is similar to that described above and depicted in Figs. 1, 3, and 4.

The effectiveness of the method and apparatus of the invention is
evident from the following discussion with reference to Figs. 1 and 3.
The size of an iceberg considered economically feasible to tow is
15   approximately one billion cubic meters. It is known that turbulent
flow greatly enhances heat transfer rates. If it is assumed that
the iceberg is 1 kilometer (km) wide, 5 km long, and 200 km deep,
that the depth of lake 21 at the point of tubes 25 in pipe 15 is
one meter, that the rate of flow of cold melt water in pipe 16 to
20   condensing unit 13 is 1000 cubic meters per second at a velocity
(V) (for turbulent flow) of one meter per second, and that the
temperature of fresh water 19 is 6°C., then the point at which flow
becomes turbulent in the instant case can be calculated from the equation -

$$R_e = \frac{LVp}{\mu}$$

25   wherein R_e is Reynold's number, L = length required to produce
turbulent flow, V = velocity, p = density, and μ = viscosity. It
is further known that flow across a plane becomes completely turbulent
when R_e = 3.7 x 10^6 or greater. Thus, in the above situation flow
becomes completely turbulent at a point 5.6 meters from the water
30   outlet at 24. Since the iceberg is 5000 meters long, flow can be
considered essentially turbulent over the entire length of the
iceberg.

The depth of the lake at outlet 24 can be calculated from the Fanning equation -

$$F = \frac{4fLV^2}{2gD}$$

wherein f is the Fanning friction factor, $D = 4S/P$ or four times the hydraulic radius, S = cross-sectional area of fluid flow = $10^7 cm^2$, and P = wetted perimeter = $10^5 cm$. It is known that Reynold's number is 2.5×10^6 for D = 400 cm, $f = 2.5 \times 10^{-3}$ and $F = 6.34 \times 10^{-1} m$. Thus, for the above situation the depth of the lake at 24 must be 1.64 m to produce a velocity (V) of 1 meter per second in pipe 16.

The heat transfer factor (j) is defined as -

$$j = (h/c_p v\rho)(c_p\mu/k)^{2/3} = S_t Pr^{2/3}$$

wherein S_t = Stanton number, Pr - Prandtl number, k - thermal conductivity, c_p = specific heat, h - heat transfer coefficient. Since,

$$S_t = (S)(t_1 - t_2)/\Delta tm (A)$$

$$j = (S)(t_1 - t_2)(Pr^{2/3})/\Delta tm (A)$$

wherein t_2 = temperature of water leaving system; tm - mean temperature difference across the film; and A = surface area over which fluid flows. For water at about 5°C., Pr = 11.0, and $Pr^{2/3}$ = 4.95. For conditions at the chilled water end of the iceberg, i.e., at 25, it is known that Re = 3.29×10^9 and j = 4.50×10^{-4}. For $\Delta tm = (t_1 - t_w)/2 + (t_2 - t_w)/2$, where t_w = temperature of the wetted wall (ice at 0°C.), $t_2 = 3.83°C$. Thus, the temperature of the water to be pumped back to condensing unit 13 is 3.83°C., and the total heat flow (Q) from the condenser water to the iceberg is 9.08×10^9 Joules per second (J/s). The heat of fusion of ice is 30.1×10^7 Joules per cubic meter (J/m^3), so the melting rate is 30.1 m^3 of ice per second. For a total iceberg volume of $10^9 m^3$,

the time required to melt the aforesaid iceberg would be 1.05 years

and the daily production of water for agricultural or other use

would be 2,210,000 m^3 (584,000,000 gal).

For the assumed rate of flow of water in pipe 16, the quantity

of heat removed from the water vapor or from the condenser working

fluid is the same as the heat available to melt ice, namely, 9.0 x

10^9 J/s, assuming no change in the temperature of the water from

iceberg to the condenser or from the condenser back to the iceberg.

Thus, the total energy available to melt the iceberg is 9080

Megawatts (Mw). For a conservative estimate of efficiency of the

above system of 2%, the actual power output available in the above

method is 182 Mw or enough electrical energy to supply the entire

power requirements of about 18,000 people for a one year period.

The amount of cold melt water that can be removed from the

iceberg for use as fresh water can be determined as follows. A

certain amount of cold melt water must be collected in a "lake" or

"reservoir" from which it is cycled to condense vapor (either water

vapor or working fluid vapor). Once a lake or reservoir of sufficient

size is obtained, cold melt water can be removed as fresh water at the

rate at which the iceberg melts. For an iceberg of the aforesaid

dimensions, about 25 cubic meters of water could be removed every

second.

It should be noted that a temperature differential of about

15°C. between the warm surface seawater and the cold melt water from

the iceberg is necessary in order that the instant method operate

successfully. Generally, the warm surface seawater will have a

temperature in the range of about 15-30°C., and the cold melt water,

in the range of 2-15°C.

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